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12a. DISTRIBUTION/AVAILABILITY STATEMENT

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13. ABSTRACT (Maximum 200 words)

A high power 95 GHz radar system, developed at the University of Massachusetts, was used to make polarimetric measurements of natural surfaces. Over the two year period of this grant the following items were accomplished:

1. The 95 GHz radar was configured into a unique system capable of simultaneously making coherent and incoherent Mueller matrix measurements.
2. The equivalence of the coherent and noncoherent measurement technique was demonstrated.
3. The polarimetric properties of various foliage targets were characterized. These included the weeping willow, the sugar maple, and the white pine tree species.
4. The polarimetric properties of various snowcover types were characterized.
5. Mueller matrix models for wet and dry snow were developed.

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POLARIMETRIC MEASUREMENTS OF NATURAL SURFACES AT 95 GHZ

Final Report

Paul S. Chang
Robert E. McIntosh

August 17, 1992

U.S. Army Research Office

DAAL03-90-G-0144

University of Massachusetts

Polarimetric measurements of natural surfaces were made at 95 GHz over the two-year span of this proposal. This data was collected with a high power 95 GHz polarimetric radar system developed by the Microwave Remote Sensing Laboratory, MIRSL [1]. Figure 1 contains a system block diagram and some system specifications. Several remote sensing applications were studied and a comparison of the coherent and noncoherent techniques for determining the Mueller matrix of a target was conducted. Polarimetric observations of foliage and various types of fallen snow were also made.

The current configuration of the 95 GHz radar system permits polarimetric measurements to be made simultaneously using coherent and noncoherent techniques. The following three features make this possible: (1) a low phase noise source, (2) a ferrite polarization switch, and (3) an adjustable quarter-wave plate.

Coherent measurement of the Mueller matrix requires a system capable of measuring the complex scattering matrix of a scene. The Mueller matrix is a square matrix comprised of 16 real numbers that completely characterize the transformation between the incident and scattered fields by the target. The measurement of the scattering matrix requires rapid switching of the two orthogonal transmitted polarizations to prevent the scene from decorrelating. A signal source with low phase noise is also required for coherent operation to prevent corruption of the scattering matrix measurement due to phase fluctuations by the transmit source.

Noncoherent measurement of the Mueller matrix requires the transmission of four polarizations, but we usually use six polarizations to reduce measurement errors. There are no time requirements in the switching between transmit polarizations if the scene being observed remains stationary in the mean for the duration of the measurement. The combination of the ferrite polarization and a quarter-wave plate is used to achieve vertical, horizontal, +45 linear, -45 linear, right hand circular, and left hand circular polarizations.

During the Summer and the Fall of 1991 simultaneous coherent and noncoherent polarimetric measurements were made on several species of trees. Figure 2 contains polarization signatures of a specimen of the Weeping Willow species. Figure 2a was calculated using the noncoherent measurement technique. Figures 2b-d utilized the coherent technique. These measurements demonstrate experimentally that the proper use of both measurement techniques leads to equivalent results[2].

The Winter of 1991-92 marked the start of a measurement campaign on fallen snow with the 95 GHz radar. The radar was mounted on a gantry on the roof top of a 30 meter high building on the University of Massachusetts campus. This vantage point provided an unobstructed view of a flat field. Incidence angles between the radar pointing direction and the flat surface ranged from 60 to 80 degrees, and 25 degrees as shown in Figure 3. In-situ measurements of the percent water content were taken coincidentally with the radar measurements.

Several snow types were encountered during this measurement campaign. The snowcover types studied can be grouped into two broad categories. The first snow type consisted of nearly spherical crystals which led to the assumption that the snowcover can be considered an isotropic volume scatterer. The scattering behavior of this class of snowcover was observed to be a function of incidence angle such that σ_{vv} became greater than σ_{hh} as incidence angle increases. To account for this behavior a model for the Mueller Matrix was developed which assumes that the snow contains scatterers that are insensitive to the orientation of the incident polarization. A simplified model of the Mueller matrix consisting of only two parameters was developed which allows the determination of the Mueller matrix using only co- and cross-polarized power measurements [3]. Figure 4 shows the polarization signatures for this isotropic snowcover for different incidence angles.

A second catagory of snowcover consisted of stellar dendrites, needles, columns, or plates. These crystal types are nonspherical and are likely to exhibit some anisotropic behavior due to their preferred fall orientation[4]. This type of snowcover does not exhibit any significant preference for σ_{vv} over σ_{hh} as incidence angle increases. The preferred fall orientation of the snow crystals gives rise to a large imaginary part in the covariance of the co-polarized scattering coefficients, S_{vv} and S_{hh}. This indicates a significant phase shift

between S_{vv} and S_{hh} and is due to either differential scattering or transmission through the snowpack. The anisotropic scattering behavior occurs for incidence angles greater than 50 degrees. Figure 5 shows the polarization signatures for incidence angles of 25 and 80 degrees. The data in figure 5a and 5b was collected the morning following a snowfall event the previous night. The snow pack consisted of 7.5 cm of dry, low-density snow comprised of nonspherical crystals. The phase shift between S_{vv} and S_{hh} introduces a twist in the polarization signature that can be seen in the 80 degree data. There is no significant phase shift seen in the 25 degree data. Figure 5c shows 80 degree data for the same snowfall event measured later in the day. The snowpack had melted from the bottom to a depth of 3.5 cm with the top layer consisting of the dry low density snow. The anistropic scattering behavior is still visible but to a lesser degree. This suggests that the magnitude of the imaginary part of the covariance of S_{vv} and S_{hh} is a function of the snowpack depth for this snow type.

The following items were accomplished during the two year period of this proposal.

1. The 95 GHz radar was configured into a unique system capable of simultaneously making coherent and incoherent Mueller matrix measurements.

2. The equivalency of the coherent and incoherent measurement technique was demonstrated. The advantages and disadvantages of both methods were explored.

3. The polarimetric properties of various foliage targets were characterized. These included the Weeping Willow, the Sugar Maple, and the White Pine trees species.

4. The polarimetric properties of various snowcover types were characterized.

5. Mueller matrix models for wet and dry snow were developed.

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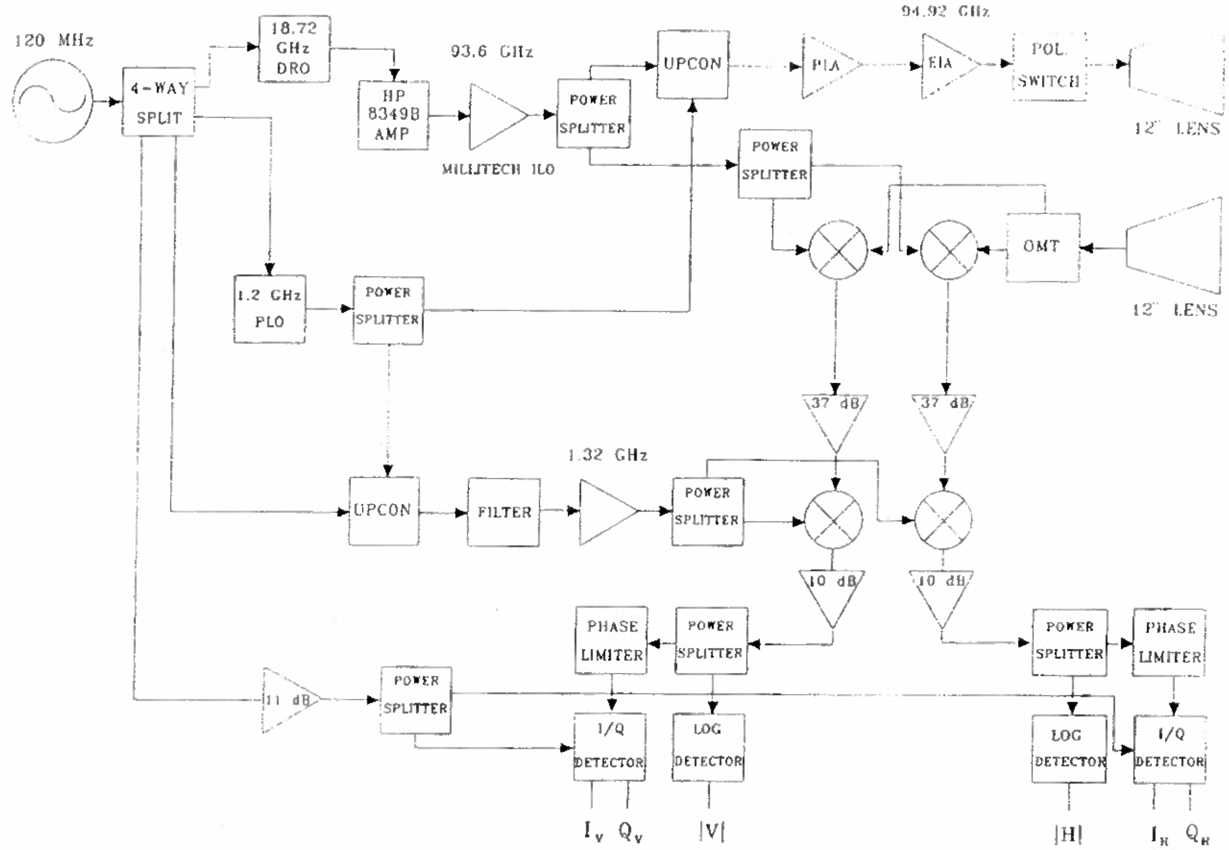


(a)

Transmitter

Source	Extended Interaction Amplifier
Frequency	94.92 GHz
Modulation	Pulse
Peak Power	1.5 kW
Maximum PRF	20 KHz
Pulsewidth	50–2000 nS

Receiver

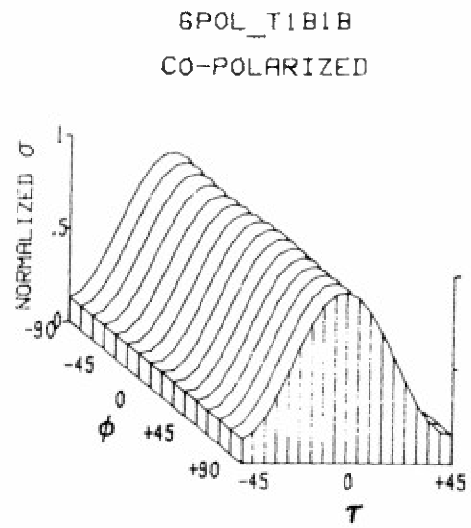
Dynamic Range	75 dB
Noise Figure	9 dB Single Sideband
Noise Floor	–101 dBm @ 20 MHz

Antennas

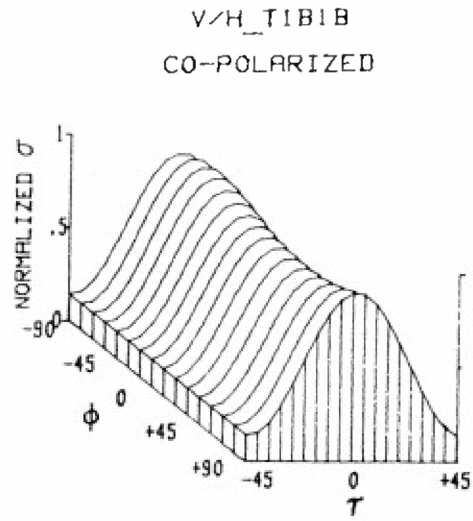
.7° Beamwidth	12" lens

(b)

Figure 1: (a) 95 GHz radar block diagram
(b) 95 GHz radar system specifications



(a)



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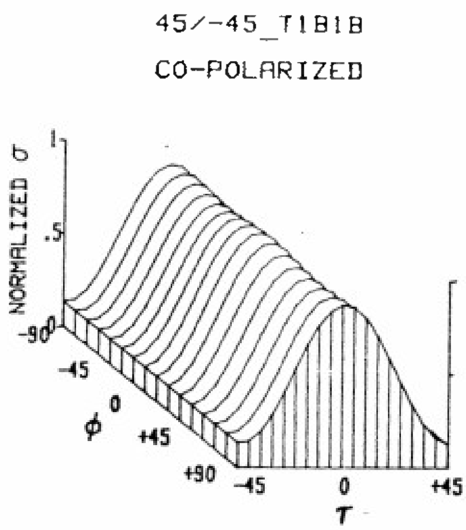

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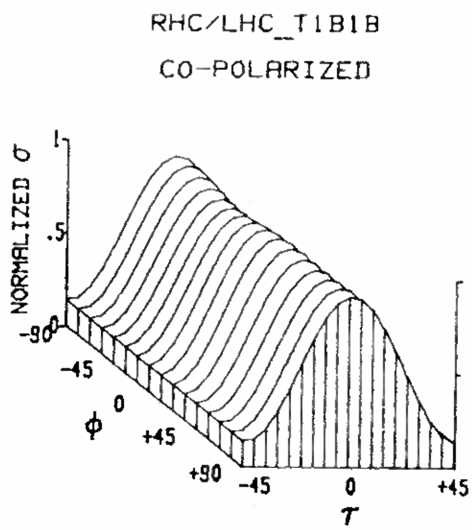


(d)

Figure 2: Polarization signatures of a willow tree

(a) noncoherent processing
(b)-(d) coherent processing
- (b) vertical/horizontal polarizations
- (c) +45 linear/-45 linear polarizations
- (d) right hand circular/left hand circular polarizations

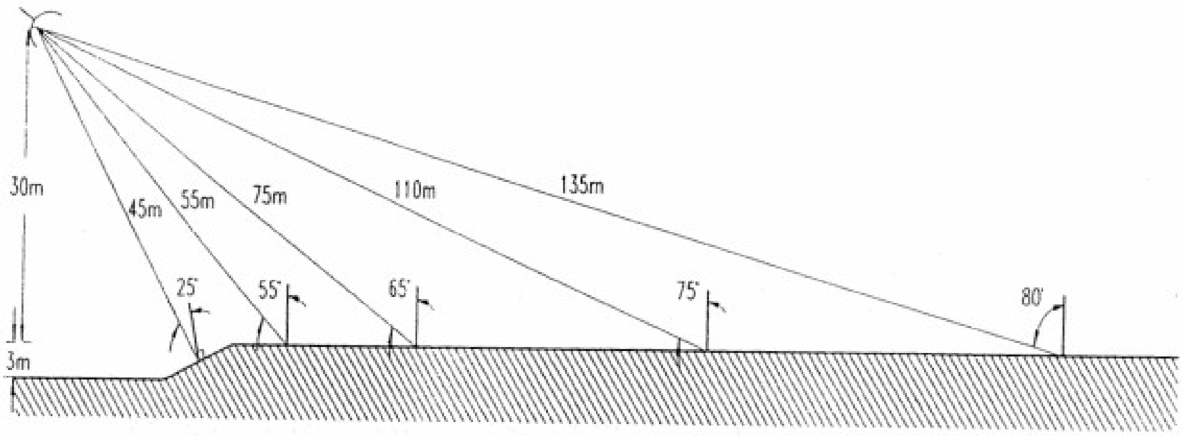
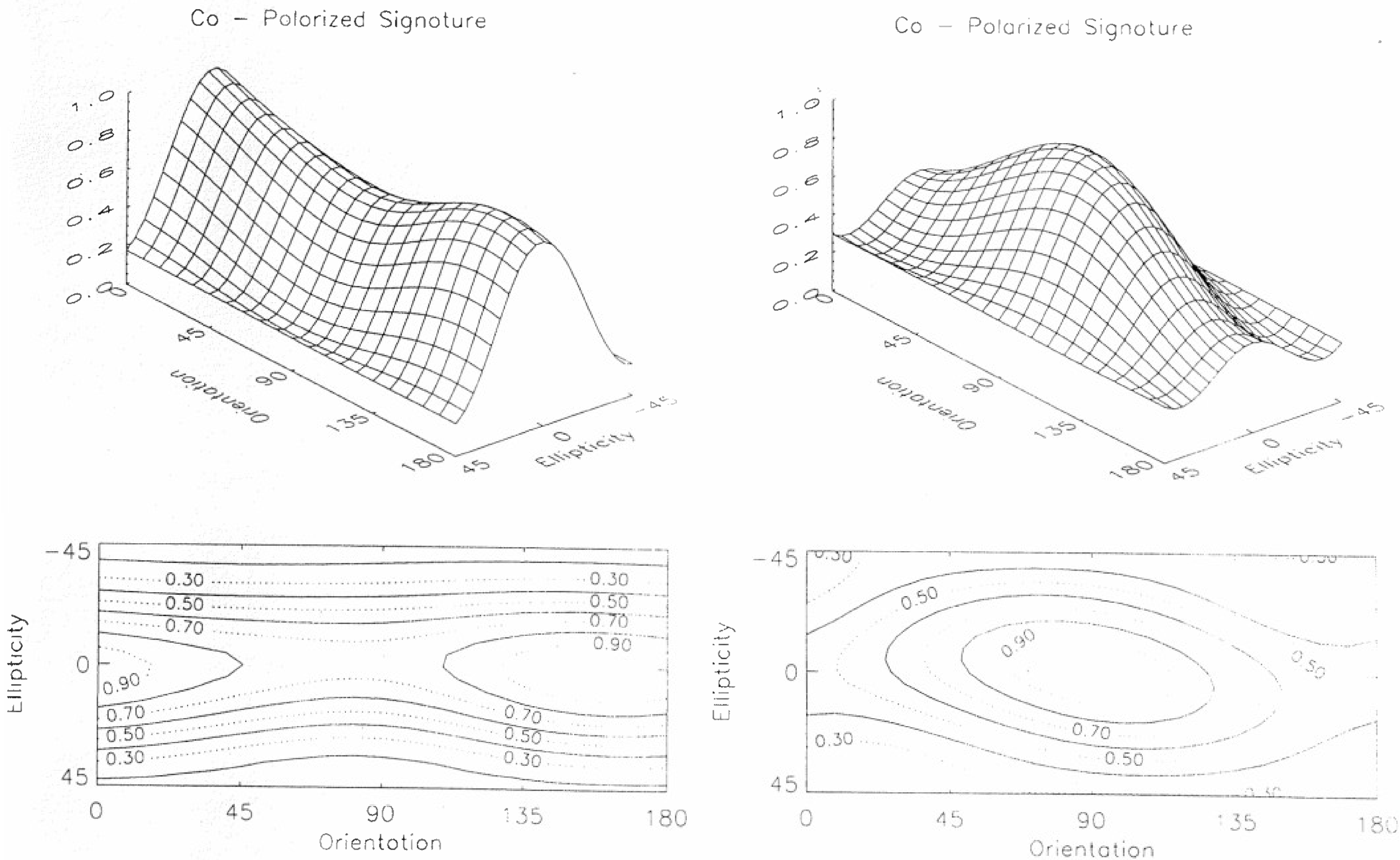


Figure 3: Geometry of snow measurement site

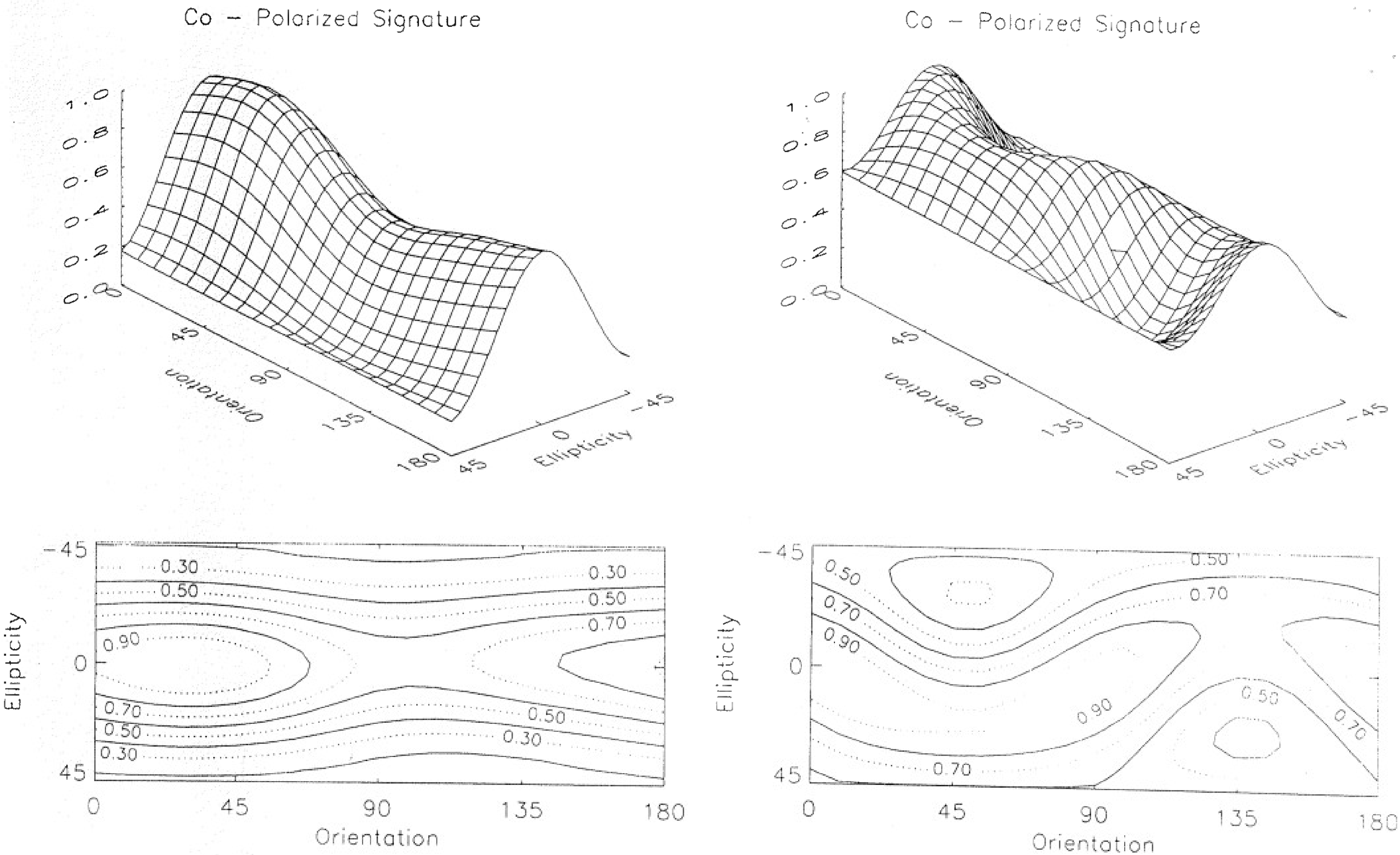


(a)

(b)

Figure 4: Polarization signatures of snowcover consisting of near spherical crystals at 95 GHz

(a) 25 degrees
(b) 80 degrees

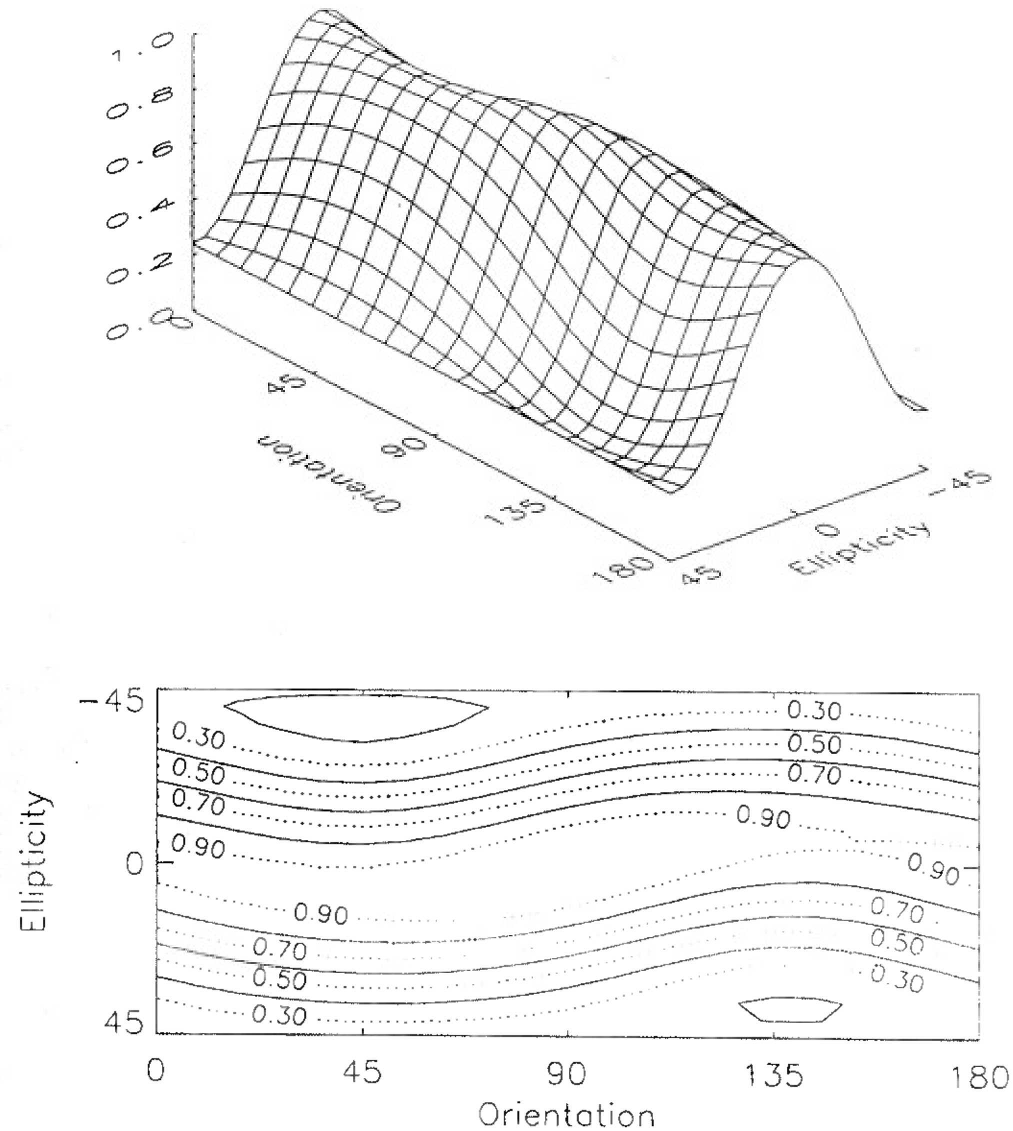


(a) (b)

Figure 5: Polarization signatures of snowcover consisting of non-spherical crystals at 95 GHz

(a) 25 degrees
(b) 80 degrees
(c) 80 degrees

Co – Polarized Signature



(c)

Scientific Personnel Supported by This Project and Degrees Awarded During This Reporting Period

Robert E. McIntosh, Professor

James B. Mead, Senior Research Fellow

Philip M. Langlois, awarded M.S. degree, May, 1991

Paul S. Chang, Ph.D. Candidate

Stephen Fraiser, Ph.D. Candidate

Stephen P. Lohmeier, awarded M.S. degree, February, 1992

Geoffrey Hopcraft, Ph.D. Candidate